Enhancement of Medium- and High-Energy-Resolution Inelastic X-ray Scattering Techniques at the Advanced Photon Source in the Near-Term Future (Summary)

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The emergence of inelastic x-ray scattering (IXS) as a set of main-stream experimental techniques has been one of the most significant developments in synchrotron radiation science in recent year. The spectrum of applications reaches from studies of lattice dynamics at the high-energy-resolution (~1 meV) end to correlated electron systems at the medium- and lower-energy-resolution (50…500 meV) end. With substantial improvements in energy- and momentum resolution and greatly enhanced momentum transfer ranges, scientific areas could be addressed that are currently inaccessible to any physical probe, including neutrons and visible light [1, 2, 3].

Upgrade of Existing Instruments

A number of dedicated, state-of-the-art IXS spectrometers are in operation at the APS, including two medium-energy-resolution instruments at 9-ID and 30-ID, one lower resolution, high-throughput instrument at 20-ID, two high-resolution facilities at 30-ID and 3-ID and a few "part-time" instruments in various sectors. In order to dramatically enhance the capabilities of these "photon-flux hungry" instruments within the next 5 years, the following technical challenges have to be addressed:

1) **X-ray Sources**. Long straight sections with additional undulators are necessary to increase the available incident photon flux proportionally. For instruments, that operate at particular fixed energies, optimized undulators need to be considered.
2) **High Heat-Load Monochromators**. With increased incident power, improved high heat-load monochromators based on synthetic diamonds, possibly with cryogenic cooling, need to be developed
3) **Secondary Monochromators**. The next step in the development of secondary, high-resolution monochromators is to advance into the sub-meV regime[3]. At the same time attention has to be paid to multiple bandpass options, to enable coarser orientation measurements at high throughput, easily switchable to high-resolution measurements in the regions of interest.
4) **Focusing Mirrors.** Beam spots at the sample need to be decreased to a few micro-meters to accommodate ever smaller samples and extreme sample environments. A small beam footprint is also important for the precision of modern energy-dispersive crystal analyzer / position-sensitive detector combinations.
5) **Sample Instrumentation.** Small beam sizes necessitate precise micro sample positioning systems, combined with in-situ crystal orientation capabilities.
6) **Crystal Analyzers**. New analyzer geometries and mass fabrication techniques for crystal analyzers have to be developed to equip/enhance existing instruments as well as pave the way for new designs, such as instruments with large numbers of analyzers.
7) **Detectors**. Silicon strip detectors in combination with energy-dispersive analyzers setups have had a great impact in making IXS spectrometers more compact without

loss of resolution while increasing throughput. These detectors need to be further developed, based on cryogenically cooled Germanium chips, to increase detection efficiency for x-rays, especially at higher energies. At the same time, this would reduce noise levels, which limit the applicability of these detectors at the lower end of the energy scale.

Implementation of novel instruments

With the development of new optical components, analyzers and new position-sensitive detection systems, novel instruments can be designed and implemented within the next 5 years, offering access to areas of science which are not accessible today.

Multi-analyzer Spectrometers. Instruments with large numbers of analyzer (> 100) combined with low-noise position-sensitive detectors can increase throughput by orders of magnitude, while being compact without loss of energy resolution. Details for such instruments can be found in [2], and also in [3].

Ultra-high Resolution Instruments. Using novel x-ray optical concepts, a sub-meV monochromator has been proposed [3] and independently, a spectrometer which can achieve sub-meV energy resolution and simultaneously unsurpassed momentum resolution [2].

Both types of instruments are logical extensions of existing IXS spectrometer designs. They would offer substantial improvements in energy-resolution, throughput, momentum resolution and available momentum transfer range and would ensure the place of the APS at the forefront of Inelastic X-ray Scattering research.

[1, 2, 3] See for example
"APS Renewal Medium-Term Proposals: Beamlines 9-ID, 30-ID, 3-ID"